ERDC/CRREL TR-09-13

Cold Regions Research and Engineering Laboratory

US Army Corps of Engineers®
Engineer Research and Development Center

Strategic Environmental Research and Development Program (ER-1481)

Propellant Residues Deposition from Firing of AT4 Rockets

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December 2009

Cover photo: Firing of AT4 at the 40/90 Range, Fort Richardson, AK, 16 March 2009 (From video taken by Art Gelvin, CRREL).

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Final report

Prepared for Strategic Environmental Research and Development Program (SERDP)
Arlington, Virginia 22203

Under SERDP Project ER-1481

Abstract: Military live-fire training missions utilize a variety of energetic materials that are never completely consumed during firing. In March 2009, tests were conducted at Fort Richardson, Alaska, to determine the residues related to the firing of AT4 anti-armor shoulder-fired rockets. Six rockets were fired from the same firing position on the snow-covered range. Replicate multi-increment samples were collected from the snow surface behind and downrange of the firing point in each of eight decision units. Samples were analyzed and results composited to derive an estimate of the mass of unreacted energetics. Total estimated per-round deposition rate of nitroglycerin (NG) for the M136 AT4 rocket is 95 g/round, or 73% of the original NG load. This indicates that the propellant burn efficiency for the AT4 is poor, with much propellant not consumed during firing. In subsequent May 2009 samples, we found approximately one-third of the NG had leached out of the propellant fragments since March. Large propellant strip segments collected in May contained 67% of the nominal NG of the original propellant, and we hypothesize that even more had leached from the more numerous, smaller segments. Canadian tests of the similar Carl Gustav rocket also indicate high rates (> 14%) of unburned propellants.

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Preface

This study was conducted for the Department of Defense (DoD) Strategic Environmental Research and Development Program (SERDP) under Environmental Restoration Program Project ER-1481. Dr. Andrea Leeson was the program manager.

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Fieldwork on active ranges is a difficult and complicated matter that requires cooperation and assistance from many people. The authors thank the soldiers and officers of the 716th Explosive Ordnance Disposal (EOD) Detachment, who fired the rockets. Without their enthusiastic assistance, this test would not have occurred. Michael Bryers and David Fitz-Enz of the U.S. Army Alaska Range Office secured access to the firing range and helped set up the tests. As always, their assistance was greatly appreciated. In the field, Art Gelvin and Nancy Perron of CRREL provided support during the winter deployment. Stephanie Saari, Sue Bigl, Ron Bailey, Charles Collins, and Alan Hewitt of CRREL and Jessequa Parker of the Alaska District, U.S. Army Corps of Engineers (USACE), participated in the spring sampling. Dr. Susan Taylor provided the magnified images of the propellant segments. Internal manuscript review was provided by Dr. Clarence Grant and Dr. Thomas Douglas. Editing was done by Jean Noellsch.

This report was prepared under the general supervision of Thomas J. Tantillo, Chief, Engineering Resources Branch, and Dr. Robert E. Davis, Director, CRREL.

The Commander and Executive Director of the Engineer Research and Development Center is Colonel Gary E. Johnston. The Director is Dr. James R. Houston.

1 Introduction

1.1 Background

The use of munitions during live-fire training is a necessary component for a well-trained military. The environmental impacts caused by the energetics associated with these munitions were not fully known until relatively recently. That knowledge was accelerated with the closure of ranges in Alaska (Eagle River Flats on Fort Richardson) and Massachusetts (Massachusetts Military Reservation) and subsequent research into the characterization of contaminants on those ranges (Racine et al. 1992; Clausen et al. 2004).

Initially, the emphasis was on the impact areas, where detonation of the projectiles had the potential to introduce large quantities of energetics into the environment. Characterization and deposition studies indicated that a properly functioning munition will not deposit appreciable amounts of energetics during training (Hewitt et al. 2005; Jenkins et al. 2006; Walsh, M.R. 2007). In the process of examining impact areas, the focus expanded to include the characterization of firing points (Walsh, M.E. et al 2001, 2007; Walsh, M.R. et al. 2005a, 2005b, 2007a). When firing positions for shoulder-fired rockets were characterized, high concentrations of propellant residues were found in the surface soils (Thiboutot et al. 1998; Jenkins et al. 2006; Wingfors et al. 2006).

The examination of firing points (FPs) as a source of energetic residues is a recent thrust in range sustainability research. Starting in 2000, studies funded by U.S. Army Alaska (Soil and Water Quality Monitoring Fund) at Fort Wainwright's Donnelly Training Area (DTA) (Walsh, M.E. et al. 2001) indicated propellant-related energetic compounds were accumulating at heavily used indirect-fire and direct-fire FPs. Further research in 2001 and 2002 (Walsh et al. 2004) reinforced the original indications, with the propellant constituents nitroglycerin (NG) and 2,4-dinitrotoluene (DNT) recovered at several FPs. The State of Alaska lists DNT as a hazardous substance.

In 2002, the U.S. Department of Defense (DoD) Strategic Environmental Research and Development Program (SERDP) funded research at Fort Richardson, Alaska, to estimate high-explosives (HE) residue deposition

(RDX, HMX, and TNT) from the live-fire detonation of 105-mm and 81-mm HE projectiles. Following the firing of the 105-mm howitzers, propellant residues containing DNT were collected from the snow-covered area in front of one of the guns (Walsh et al. 2004). Results indicated concentrations of energetic residues four orders of magnitude higher for the firing points than found at the impact areas (Hewitt et al. 2003; Walsh et al. 2005b; Walsh, M.E. et al 2007).

The ease of sample collection on snow and the straightforward processing of these samples led us to consider further investigations at winter firing points as an adjunct to the impact area research we were then conducting for SERDP. The methodology for the collection of samples on snow originally developed by Jenkins et al. (2000a, 2000b, 2002) was optimized by M.R. Walsh et al. (2005a, 2007b), making sampling much more efficient and repeatable.

Trials have been conducted on several common weapon systems including howitzers (M.R. Walsh et al 2005b; Diaz et al 2008), mortars (M.R. Walsh et al. 2005c, 2006), small arms (M.R. Walsh et al 2007a; Brochu et al. 2009), and tanks (Ampleman in prep.). Results of studies conducted at shoulder-fired rocket positions on training ranges indicated concentrations of NG up to 1,400 mg/kg. When comparing that finding to that of 500 mg/kg for heavily-used small arms ranges and <10 mg/kg for artillery positions, it was clear that more information was required on the impacts of the shoulder-fired rockets (Jenkins et al. 2007).

Canadian researchers at the Defence Research and Development Canada (DRDC) had conducted deposition trials in 2007 for the Carl Gustav shoulder-fired rocket and in 2008 for the M72 LAW rocket, indicating moderate to high levels of residues (Thiboutot et al. 2008a, 2008b). Additional work on U.S.-inventoried shoulder-fired rockets thus was deemed necessary.

1.2 Objectives

Because of the need for continued training with live ammunition at military ranges, the need for Army Range Officers to manage residues from such training lands, and the identified problems with depositions from the use of shoulder-fired rockets, further investigations of residues from the firing of shoulder-fired rockets were initiated, including the

deposition of unburned propellants resulting from the firing of these weapons (Thiboutot et al. 2007).

This report details a propellant residues deposition test conducted at Fort Richardson, Alaska, in March 2009. This report documents follow-on work to the previous studies by examining the propellant residue deposition rate for the U.S. Army's M136 AT4 shoulder-fired rocket.

The objective of this work is to provide data and results that can be used by the range community to assess the environmental impact of training with the AT4 rocket. This information then can be used to develop an integrated training lands management plan.

1.3 Approach

The AT4 propellant residues testing was conducted in 2009 during two deployments. We first visited the Fort Richardson, Alaska, 40-mm/AT4 Range (40/90 Range)[1] for live firing of the weapons systems in March 2009. We returned to the same site in May 2009 to resample the area behind the winter firing position in order to gauge the natural decomposition of the depositions from exposure to weather.

It was our original intent to sample downrange all the way to the target, but evidence of unauthorized use of the target by 40-mm grenade gunners prohibited traveling downrange beyond a few meters of the parking area. The snow cover masked prior activities and rendered this task unsafe.

Processing of the March samples was performed at a CRREL field laboratory located in our logistics building on Fort Richardson prior to final processing and analysis at CRREL's analytical laboratory in Hanover, NH. Processing of the snow samples in Alaska greatly reduced the quantity of sample material that needed to be shipped to the analytical laboratory. The soil samples collected in May were shipped directly to the CRREL laboratory in Hanover for processing and analysis. Sections 2 and 3 of this report provide detail for the sampling procedures, and the processing and analyses of those samples.

[1] The location and time of the first visit were chosen due to previously documented results in being able to easily collect more residues from a snowy surface.

It is important to note there were no baseline samples of the soils in the area taken prior to snowfall, so we are uncertain if NG was present at the location prior to our test.

2 Field Sampling Methodology

2.1 Field site and conditions

No activity had occurred at the Fort Richardson range during the winter immediately prior to our test. For the March test, the parking area had been plowed, but a recent snowfall had deposited 3 cm of snow on the surface. We set the firing position on the top of the up-range snow berm that was formed during the several snow clearing operations of the parking area. The FP configuration was designed to minimize snow displacement and mixing from the backblast of the rocket firing. The snow surface behind the firing position sloped away for 3 m, leveled out for about 10 m, then sloped abruptly down less than a meter to the natural grade (Figure 1). Forward of the firing position, the area was flat for 18 m before encountering the opposite snow berm. The temperature at the time of testing was around –7 °C with winds out of the north variable at around 4 m/sec. The sky was heavily overcast at the start of the test, clearing as the day progressed. Snow depth was less than 40 cm outside the berms and 3 cm on the plowed parking area. Berm height was approximately 1.5 m.

Figure 1. Looking at backblast area from snow berm near firing position.

Following the natural snow melt, the site in May 2009 was revealed to consist of two areas – one-half of the sampled area was a gravel pad, the remainder was brush-covered soil (Figure 2). Weather was not a factor during this second sampling because we were not firing rockets but only were collecting soil samples from the previous test in March.

Figure 2. Backblast area in May 2009 prior to sampling.

2.2 Munitions tested

The munitions tested were M136 AT4 shoulder-fired rockets, drawn from stock at Fort Richardson ammunition supply point by soldiers of the 716th Explosive Ordnance Disposal (EOD) detachment (Table 1). Each weapon system consisted of a launcher and an 84-mm high-explosive anti-tank (HEAT) round. The round contained 355 g of AKB 204 propellant configured in 200 strips 15-mm thick by 167-mm long. The propellant is double-base, with a nominal composition of 61% nitrocellulose (NC), 37.5% nitroglycerin (NG), and 1.5% ethyl centralite (EC), a stabilizer and waterproofing agent. (Appendix A contains complete munitions data for this test.)

Table 1. Propellant constituent for munition used during firing point test.

Weapon	Munition (Mil / DODIC)	Propellant	Constituent	Constituent Load (g / % of total load)
AT4 Shoulder-fired Rocket	M136 / C995 (HEAT)*	AKB 204	NG	133 / 37.5%

*HEAT: High-Explosive Anti-Tank warhead

2.3 Rocket firing test

Rocket firing was conducted the morning of 16 March 2009. As previously stated, we were assisted by soldiers of the 716th EOD detachment. Range access was granted for the full day by the U.S. Army Alaska Range Office.

Prior to the firing, a background snow sample was collected from the back-blast area behind the designated FP. (A detailed description of the sampling method is in the following section of this report.)

Traffic around the firing points was kept to a minimum and restricted to established paths. The snow berm surrounding the parking area was utilized to minimize the effect of the backblast on the sampling surface by elevating the firing position above most of the surrounding snow surface (Figure 3). The weapons were fired when the wind slacked to minimize dispersion of the propellant residues.

We were unable to follow our original intent to sample downrange all the way to the target, because of evidence of unauthorized use of the target by 40-mm grenade gunners. This prohibited traveling downrange beyond a few meters of the parking area, as the snow cover could mask prior activities and rendered this part of the task unsafe.

Figure 3. AT4 Firing position on snow berm.

Following the firing of the rockets, decision units (DUs) were set up for sampling. A total of eight DUs were demarcated, three behind the firing position and five downrange (Figure 4). The plume areas were demarcated by packing a path through the snow around the extent of propellant residues visible on the snow surface, a procedure known as visual demarcation. The outside-the-plume (OTP) sampled areas were 0-3 and 3-6 m from the plume periphery. Where the front and back plume met, the OTP annuli were truncated. Two 3- x 10-m transects were located 40- and 50-m downrange from the firing position. The plumes and transects were recorded using a Trimble GPS Pathfinder Pro XR system (±1-m) supplemented with hand measurements taken with a tape. Areas of the DUs are given in Table 2.

Table 2. Decision unit areas – March 2009.

Decision Unit	Area (m^3)
Back Plume – Plume	410
Back Plume – 0-3 m OTP*	250
Back Plume – 3-6 m OTP	270
Front Plume – Plume	390
Front Plume – 0-3 m OTP	240
Front Plume – 3-6 m OTP	260

Decision Unit	Area (m^3)
Downrange Transect FPT-1	27
Downrange Transect FTP-2	25

*OTP: Outside the plume – An annular area outside the demarcated plume

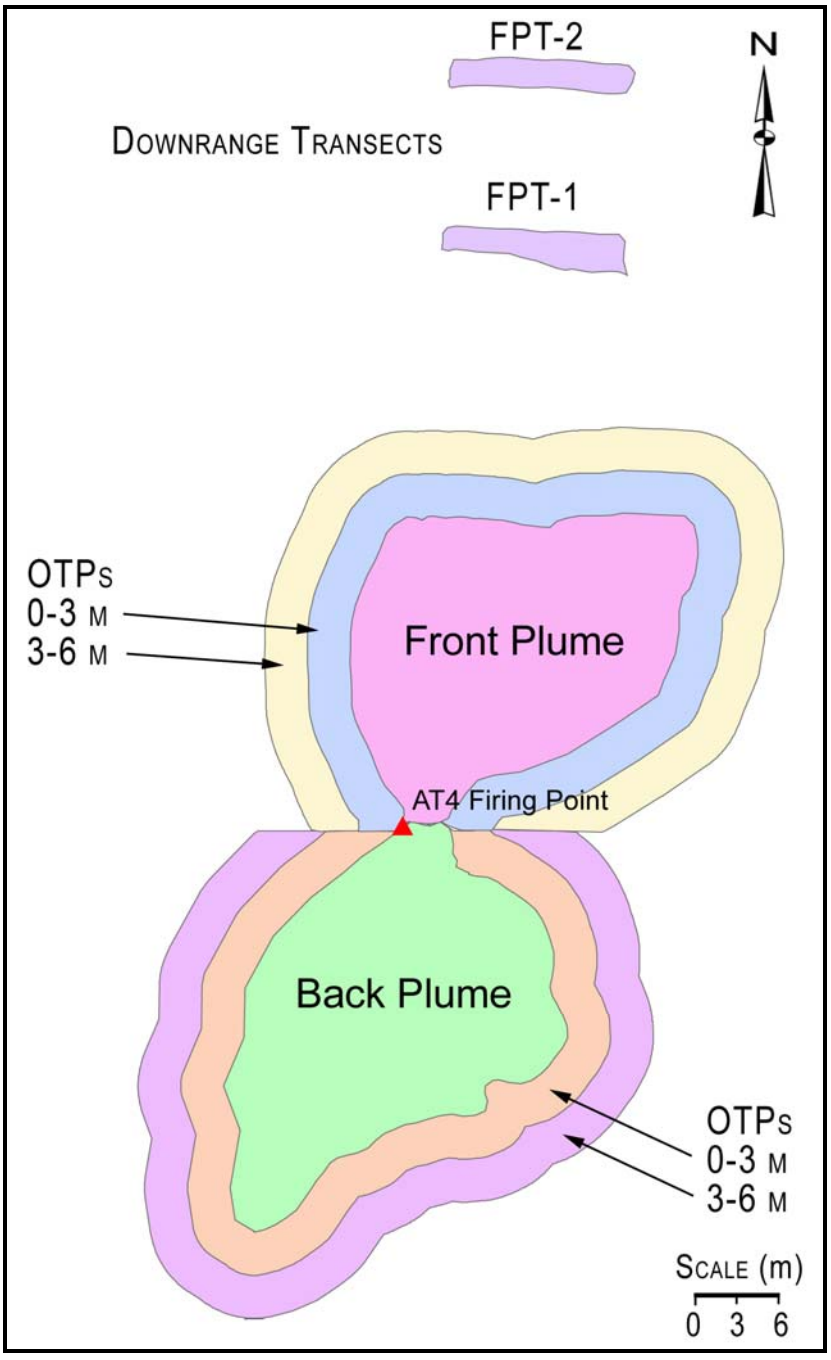


Figure 4. Sampling decision units for AT4 test – March 2009.

Follow-up sampling was conducted in May 2009. A 30 x 30 m DU was created in the back plume region behind the AT4 firing position (Figure 5). A set of three systematic-random multi-increment samples were taken from this area to determine residue loads. Because no background samples of the soils in the area were taken prior to our test in March, this sampling will characterize the site rather than give us rigorous depositional information.

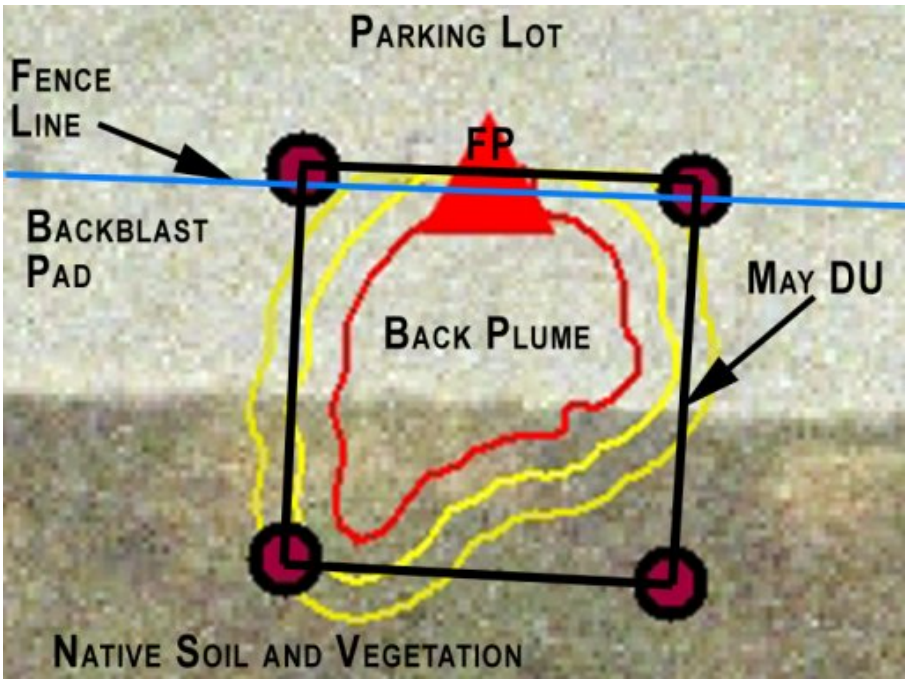


Figure 5. May 2009 decision unit (DU) superimposed over March DUs (red and yellow outlines).

2.4 Sampling method

The March sampling was done on a fresh snow surface following the multi-increment sampling (MIS) protocol established by M.R. Walsh et al. (2007b). Briefly, 30 to 100 increments of surface snow were collected with a 10- x 10-cm scoop, to a depth of 2.5 cm, to make up a single sample within a DU (inside the demarcated plume, outside the plume, within transects, etc.), until the area is representatively sampled. The increments for a given sample are collected in a single clean polyethylene bag to make up the MIS. MIS allowed us to test and compensate for uncertainty derived from the small total area collected from within each decision unit, typically less than 1 m^2.

To estimate the depositional mass of energetic residues, we needed to know the area over which the energetic material is deposited and the average concentration for that area. A critical assumption is that the visible plume represents the major area of deposition. The plume is composed of deflagration products, and its depositional pattern will be affected by wind. However, because there is no other way to estimate the area of deposition, we assume that most residues are deposited within the plume. This assumption was tested by taking multi-increment samples from concentric annuli outside the demarcated plume. The objective of OTP sampling is to determine how much, if any, of the unconsumed energetics are measurable outside of the plume. Replicate samples were obtained for the two 3 m annuli for both the front and back plumes. The 10- x 10-cm scoops were used to a depth of 2.5 cm for each increment.

Subsurface samples were also taken to estimate how much residue was missed by sampling only the top 2.5 cm of snow. A sample increment was first taken with a 20- x 20-cm scoop. From the center of the sampled area, a 2.5-cm deep sample was taken with a 15- x 15-cm scoop, thus obtaining a "subsurface" sample. These subsurface increments were deposited into a clean bag as a separate sample.

In the spring, soil samples were taken from the backblast area behind the AT4 firing position. Systematic-random MIS was used to characterize the site (M.E. Walsh 2005; Jenkins et al. 2005). The 30- x 30-m decision unit was broken down into ten 3-m wide lanes. The location of the starting point was randomly selected for each of the three samples from within the first 3- x 3-m "cell" and an increment systematically taken in each of the remaining 99 cells based on the starting increment location. The area consisted of two types of soils, so two different sampling tools were used. On the gravel pad directly behind the firing position, #2 stainless steel scoops (AMS #428.02) were used to collect unconsolidated material from an area approximately 3- x 3-cm to a depth of 2 cm. In the area containing cohesive soils, a 3-cm CRREL multi-increment sampling tool was used to collect 3-cm diameter x 2.5-cm deep cores (Figure 6). Both types of increments were deposited in the same bag to construct a sample.

Figure 6. Sampling backblast area in May 2009.

2.5 Propellant segment samples

Following the cessation of firing in March, a few large segments (≈1 cm long) of what appeared to be propellant strips on the snow surface in the backblast area were collected for analysis. Several small segments were also collected from the snow surface and stored in a refrigerator at the field lab for later chemical and optical analysis as well as for future dissolution tests. A snow sample that contained a large amount of propellant debris was collected from the back plume area (Figure 7), specially packed for transport, and sent for further analysis and study at the analytical laboratory in Hanover (CRREL). Meanwhile, at the field laboratory on Fort Richardson, one of the large segments was dried and tested with an Expray kit (Plexus Scientific, Alexandria, VA) for NG.

Figure 7. Propellant debris on snow in back plume following rocket firing. Edge of scoop is 10 cm long.

In May, a cursory visual search of the backblast area near the firing point was conducted to collect propellant previously present on the snow surface after the winter firing. Most of the debris observed in the winter was <0.5 cm, small enough to fall between the cobbles on the gravel backblast pad immediately behind the firing position. However, two large (>1 cm) segments were found after a brief search and placed in plastic bags for the dissolution study and chemical analysis work at CRREL's analytical laboratory.

3 Sample Processing and Analysis

3.1 Snow samples

The samples of snow were transferred to a laboratory at the Fort Richardson cantonment area for processing. Upon arrival, the samples were transferred from the field bags to clean bags, double-bagged, and placed in clean polyethylene tubs for thawing. Placing the samples in clean bags reduces the chances of cross-contamination from contact with adjoining bags and residues on the exterior of the sample bags. Double-bagging and the tubs were necessary because of the inclusion of sharp pieces of debris collected with the snow samples. Otherwise, gravel particles or plant stems could pierce the sample bags, allowing the thawed sample to leak.

Samples were shifted from warmer to cooler areas of the lab's logistics bay to prevent over-warming (temperatures >10 °C) after melting. The samples were then processed based on completion of melting and the sampled area they were taken from. Samples anticipated to have the least residues were processed first and those anticipated to be more contaminated were done last to reduce the possibility of cross-contamination.

Processing involved filtering the melted samples using a vacuum system to separate the particle (solids) fraction from the aqueous fraction (Figure 8). The particle fraction was collected on filter papers (Whatman glass microfiber 90 mm ∅ grade GF/A). Following filtering, the papers were placed in a clean amber jar, dried, and stored in a refrigerator at <5°C. The aqueous fraction was recorded prior to mixing and decanting of two or four 500-mL aliquots into glass amber bottles. (Two bottles were the normal number collected for analysis, four were collected for a laboratory quality assurance procedure.)

One (or three) 500-mL aliquot of the filtrate was pre-concentrated by passing it through a Waters Porpak RDX (Sep-Pak, 6-cm^3, 500-mg) solid-phase extraction (SPE) cartridge and eluted with 5 mL of acetonitrile (AcN), resulting in a 100:1 concentration of the analytes (Walsh and Ranney 1998). The concentrate was split into two aliquots, 3.5 mL for analysis and 1.5 mL for archiving. When processing was completed, the 3.5-mL splits and the filters were shipped to the CRREL's analytical chemistry laboratory in Hanover, New Hampshire, for final processing and analysis.

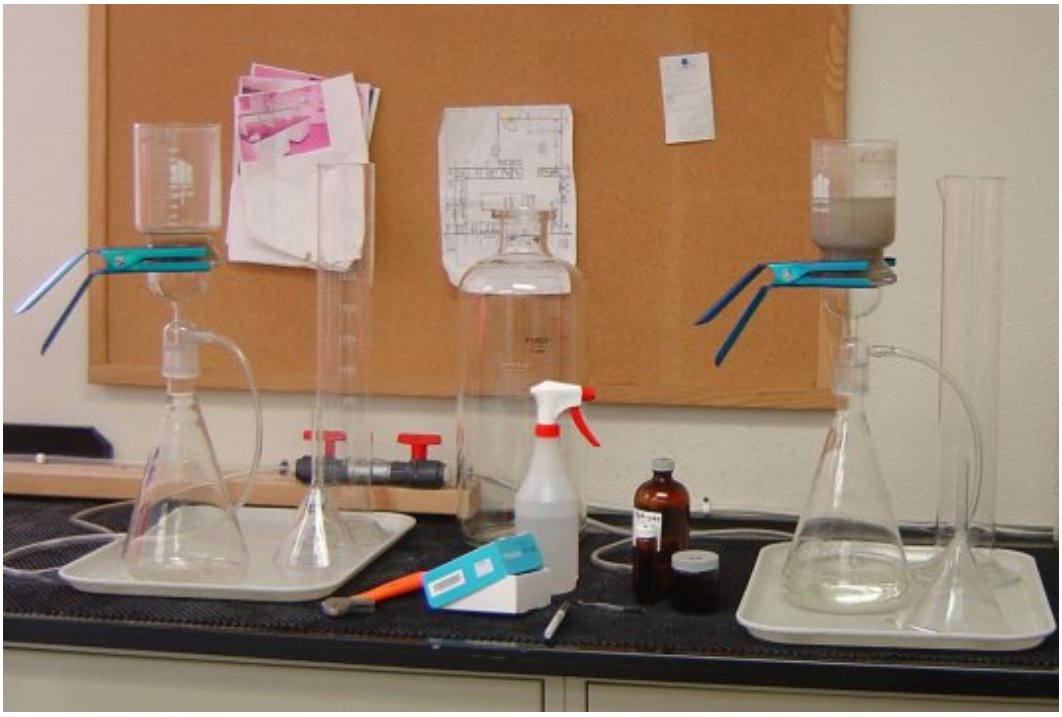


Figure 8. Snow sample filtration setup at the CRREL analytical laboratory.

The filters containing the solids were extracted after shaking for 18 hours using AcN. The AcN extracts from the solid phase extraction of the melted snow and of the solid residue on the filters were analyzed by high-performance liquid chromatography (HPLC). Analyte concentrations were determined following the general procedures of SW 846 Method 8330B to determine nitroaromatics, nitrate esters, and nitramines by HPLC (USEPA 2006). The HPLC method has an analytical error that is very small, about 2% relative standard deviation (RSD) for replicate injections.

To prepare for the HPLC analysis, 1 mL of each AcN extract was mixed with 3 mL of reagent-grade water. Determinations were made on a modular system from Thermo Electron Corporation (Waltham, MA) composed of a Finnigan SpectraSYSTEM Model P4000 pump, a Finnigan SpectraSYSTEM UV2000 dual wavelength ultraviolet/visible absorbance detector set at 210 and 254 nm (cell path 1 cm), and a Finnigan SpectraSYSTEM AS300 autosampler. Samples were introduced with a 100-µL sample loop. Separations were achieved on a 15 cm x 3.9 mm (4 µm) NovaPak C_8 column (Waters Chromatography Division, Milford, MA) at 28 °C and eluted with 1.4 mL/min of 15:85 isopropanol/water (v/v).

Calibration standards were prepared from analytical reference materials obtained from Restek Corporation (Bellefonte, PA). The analytical refer-

ence materials were 8095 Calibration Mix A (1 mg/mL) and a single-component solution of NG (1 mg/mL). A spike solution at 1 mg/L was prepared from 8095A Calibration Mix and the single-component solution of NG. Spiked water samples at 0.002 mg/L were prepared by mixing 1.0 mL of the spike solution to 500 mL of water in a volumetric flask. Following SPE, the extract target concentration was 0.20 mg/L for each analyte.

To calculate the mass of unreacted energetics deposited on the snow, we calculated the mass of the samples (mg) by multiplying the extract concentration (mg/L) by the volume of AcN (L) for the extraction (soot fraction) or the volume (L) of water from the snowmelt (aqueous fraction). These masses were then divided by the actual area sampled with the scoops (m^2) to get a surface concentration in mg/m^2. This value was multiplied by the measured area of the DU to derive our estimates of the mass within the area sampled (mg) (Jenkins et al. 2002; Hewitt et al. 2003). For the HPLC, the detection limit was 0.05 mg/L for NG in the AcN extract. Values below this limit are labeled as "ND" in the data, indicating "no detectable" analyte.

3.2 Soil samples

Soil samples were double-bagged and shipped to CRREL's analytical laboratory for processing and analysis. The samples were opened and spread out to dry on aluminum foil covered trays to dry at room temperature. The dried material was then sieved under a hood with a #10 sieve to separate out the <2-mm fines from the larger material. The fines were ground using a Lab-Tech Essa LM-2 puck mill equipped with a B800-mm metal bowl, processing 500 g of material or less for five 60-second grinds with a 2-min minimum cool-down time between grinds. The ground material (< 75 µm) was then spread in a 1 cm layer over clean aluminum foil and 30 increments taken by spatula using MIS to obtain a 10-g subsample, which was placed in a 2-oz. wide-mouth jar. AcN was added to the subsample and the jar agitated for 18 hrs on a shaker. Prior to analysis, 1.0 mL of extract was mixed with 3.0 mL of MilliQ water and filtered. The HPLC separations were achieved using a 15 cm x 3.9 mm (4µm) NovaPak C_8 (Waters Millipore) column eluted with 1.4 mL/min 15:85 isoproponol:water at 28 °C. The oversize fraction (>2 mm) was processed using whole-sample extraction with AcN. Detection was by ultra-violet (UV) light at 210 nm for NG.

3.3 Propellant samples

After collecting the debris samples from behind the firing position in March, the propellant segments were tested at our field laboratory for the presence of NG using an Expray kit. A large segment of debris was placed on a filter paper and sprayed with reagent to indicate the presence of NG. The resultant red coloration indicated a high content of NG within the larger debris (Figure 9). The remaining discrete debris pieces, as well as the debris contained in the snow sample collected for later analysis, were assumed to be unburned propellant particles worthy of further analysis and testing at CRREL's analytical laboratory. The remaining particle samples were left in sealed jars and stored on site in a refrigerator, and the snow sample was stored in a chest freezer pending later analyses.

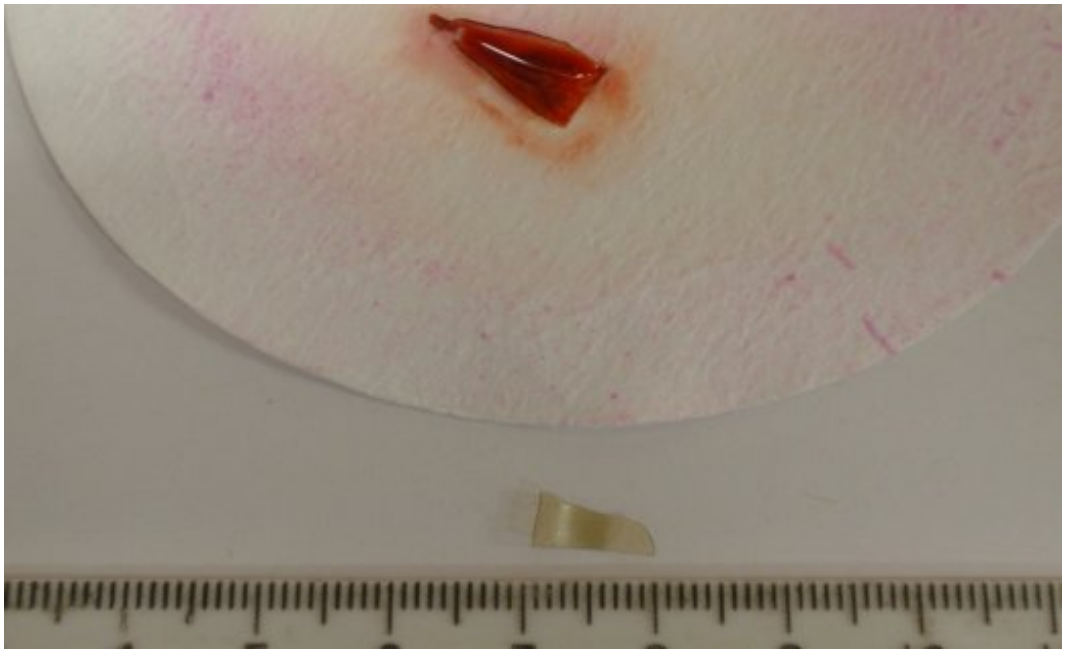


Figure 9. Pieces of propellant found in backblast area following firing. The top segment was sprayed with Expray reagent (Red = NG) – March 2009.

At CRREL's analytical lab, the large propellant pieces collected in March and May were photographed (see Appendix D). The small snow sample was placed in a filtration unit and the melting snow was filtered through a glass fiber filter using a vacuum filtration system (see Section 3.1) to separate the propellant debris from the melted snow (Figure 10). The aqueous volume was measured and stored for later analysis. The solids were air-dried for another study related to this research. The two weathered pieces collected in May, seven of the larger pieces collected in March, and the

aqueous fraction from the stored snow sample were all analyzed using the HPLC setup and procedure described above.

Figure 10. Set up at CRREL's laboratory for filtering propellant debris from March snow sample.

3.4 Quality control procedures

Quality control (QC) procedures were conducted both in the field and in the laboratory. Field QC, noted previously, included replicate sampling within the residue plumes, sampling outside the demarcated plumes, and sampling beneath the sampling points in the back plume for one sample. In the processing laboratory, blank samples consisting of filtered water from a reagent water filtration system were periodically run through a filter assembly and SPE setup for later analysis at the laboratory. This procedure was designed to determine whether cross-contamination from the sample filtering apparatus was occurring. Water fractions for several samples were divided into three aliquots and run through the SPE to determine whether recovery rates from the SPE procedure were consistent. SPE spikes were run to determine cartridge filter retention and recovery. These processes are described in greater detail in Walsh (2007). One background sample was taken in March to determine the concentration of the analyte in the areas to be sampled prior to the test.

4 Results

The background sample collected from the downrange FP area prior to firing contained no detectable nitroglycerin, indicating a clean test area.

4.1 Deposition rate

A total of 21 multi-increment samples, composed of 1,035 increments over a combined area of 1,872 m^2 in eight DUs, were taken to determine the deposition and distribution of NG from the firing of six rockets. The winter DUs ranged from 25 m^2 for the downrange transect FPT-2 to over 400 m^2 for the backblast plume (Table 2). The large back plume is the result of the open-ended recoilless design of the shoulder-fired rocket. The propellant is mostly burned prior to the projectile leaving the launch tube. Thus, much of the gas and residues from firing the rocket are directed behind the firing position. A map of the test area derived from the GPS data was shown in Figure 4.

Analytical data averaged for the replicate samples are given below in Table 3. The largest estimated average mass of NG residues lies within the backblast plume, with the remaining areas containing less than an order of magnitude additional residues. In the backblast area, the subsurface and OTP masses are not significant. For the downrange area, the OTPs are significant, but the transects are not.

Table 3. NG Residue mass for test decision units.

Decision Unit	DU Area (m^2)	Sampled Area (m^2)	Replicates	Est. Average Mass NG (mg)
Backblast Areas				
Back Plume	410	1.0 (0.24%)	4	530,000
Plume subsurface	410	0.70 (0.17%)	1	1,200
OTP 0-3 m	250	0.39 (0.16%)	2	1,300
OTP 3-6 m	270	0.46 (0.17%)	2	360
Downrange Areas				
Front Plume	390	0.50 (0.12%)	3	34,000
OTP 0-3 m	240	0.40 (0.17%)	2	3,800
OTP 3-6 m	260	0.40 (0.15%)	2	2,100
Transect FPT-1	27	0.38 (1.4%)	2	0.19
Transect FPT-2	25	0.40 (1.6%)	2	–ND–

An analysis of these results is given in Table 4. The results were composited as meta-decision units (MDUs) for comparison. For the first MDU, the surface mass of the back plume is 530,000 mg. This constitutes 99% of the NG mass in the backblast area MDU and 92% of the total mass over all DUs. There are 88 g of NG per round in the back plume, which is 67% of the original NG load for each round. The subsurface sample taken in the back plume indicates that 1,200 mg of NG lies beneath the sampled depth of the plume. This constitutes 0.23% of the total mass for MDU #1 and also of the plume, and 0.21% of the NG mass for the whole test. The contribution to the deposition rate is only 0.2 grams/round (g/rnd), or 0.15% of the total NG residue mass per round. Downrange, the 0-3 m OTP had a total estimated mass of 3,800 mg NG, constituting 9.5% of the total for the MDU, 11% of the mass of the front (downrange) plume, and 0.7% of the mass for the whole test. This contributes 0.63 g/rnd or 0.41% to the total deposition rate. Although significant for the downrange MDU, its contribution is not significant to the overall deposition rate estimate. The downrange transects contribute very little to the totals and are not significant on a per-round basis and not likely significant overall.

Table 4. Contributional analysis of the results

Meta DU (MDU)	Decision Unit (DU)	Est. Avg. NG Mass (mg)	Mass for MDU (mg)	For MDU Only	As a % of the MDU Plume	As a % for Whole Test	Deposition Rate (g/rnd)	Deposition Rate (%)
	Background	-						
MDU #1:								
Backblast	Plume B/S	530, 000		99%	—	92%	88	67%
	Plume B/U	1,200		0.23%	0.23%	0.21%	0.20	0.15%
	OTP B: 0-3 m	1,300		0.25%	0.25%	0.24%	0.22	0.17%
	OTP B: 3-6 m	360		0.07%	0.07%	0.06%	0.060	0.05%
	Total: Backblast		**530,000**			**93%**	88	**67%**
MDU #2								
Downrange	Plume D/S	34,000		85%	—	6.0%	5.6	4.3%
	OTP D: 0-3 m	3,800		9.5%	11%	0.7%	0.63	0.48%
	OTP D: 3-6 m	2,100		5.4%	6.3%	0.4%	0.36	0.27%
	Total: Downrange		**40,000**			**7.0%**	6.6	**5.0%**
MDU #3								
Transects	FPT-1	0.19				0.000034%	<0.001	<0.01%
	FPT-2	-ND-				0.00%	0.00	<0.01%
	Total: Transects		**0.19**			**0.000034%**	<0.001	**<0.01%**
All Plumes	Total: Plumes	560,000			99%		93	71%
All DUs	**Total: All**	**570,000**			**—**		**95**	**73%**

Overall, MDU #1, the backblast area, contained 93% of all the NG residues, amounting to a little over 88 g/round or 67% of the initial NG load of the round. Down range, MDU #2 contained 7% of the NG residues or 6.6 g/rnd, 5.0% of the rocket's initial NG load. This totals up to 95 g or 73% of the original NG load for each rocket. This is an order of magnitude higher deposition rate than we have seen for the scores of tests conducted over the last 10 years on various weapon systems.

To verify the validity of these numbers, we looked at the mass of the solids material recovered from the melted snow samples. The backblast area contained 93% of the NG residues so we will examine that data. The solids portion of the samples contained over 96% of the recovered NG (see Appendix B). The mass of solids residues on the filters averaged 4.72 g for the four surface samples (Table 5). Using the mean NG content of the propellant (36.5%), the average theoretical NG content of the solid mass should be 1.72 g. The average recovered is 1.31 g. This is 76% of the expected mass of NG in the residues, if we assume that all the residues are raw propellant. From an examination of the material on the filters based on color and geometry of the particles, we estimated about 80% of the material was unburned propellant (Figure 11). Using this estimate, we get an average 95% agreement between what the analyses determined and what the filter mass indicates.

Table 5. NG mass estimate for filter residues prior to processing and analysis.

Sample	Solid Residue on Filter (g)	Theoretical NG on Filter (36.5% NG)	Estimated NG on Filter (g)	Agreement Est. : 36.5%	Agreement: Assume Solids 80% Propellant
Back Plume 1	5.25	1.92	1.37	71%	91%
Back Plume 2	4.62	1.69	1.29	76%	95%
Back Plume 3	4.98	1.82	1.41	77%	97%
Back Plume 4	4.01	1.47	1.16	79%	99%
Average:	**4.72**	**1.72**	**1.31**	**76%**	**95%**

Figure 11. Filtered mass from back plume sample. Beige material is propellant. Filter paper is 90-mm in diameter.

4.2 May site characterization

Three multi-increment, surface soil samples (2.5 cm deep) were collected from within the backblast area in May 2009, two months after the firing test. The DU encompassed the entire back plume and the first OTP (0-3 m) as well as significant portions of the 3-6 m OTP area (refer to Figure 4). The overall area of the May DU was 900 m^2. The three MIS were composed of 100, 100, and 101 increments. The average concentration of NG in the samples was 13 µg/g (Appendix C). The estimated mean mass in the 30- x 30-m^2 DU was 250 g. If all the residues present in the DU are from the winter firing, the average mass of NG per round is 42 g/rnd, or 48% of the estimated mass in the area from the winter firing. No baseline sample was taken from the soil in the backblast area in the fall prior to our tests, so it is unknown what the NG levels were prior to our test.

4.3 Analysis of propellant segments

Analyses of the propellant debris collected in March and May confirmed the qualitative indication (given by the Expray test) that the material on the snow surface was mostly raw propellant. The five “fresh” particles collected from the snow surface immediately after the test in March con-

tained on average 99% of the expected amount of NG for an unburned piece of AKB 204 propellant with a nominal NG content of 36.5% (95% if the NG content is 38%). This agrees with the results depicted in Table 5 for 36.5% NG propellant content. The "weathered" particles collected 61 days later in May contain 66% of the NG load for 36.5% content (Table 6). This is an approximate 33% loss of NG over the time period.

Table 6. Results of unburned propellant analyses.

Date Collected	ID	Propellant Mass (mg)	Nominal (36.5%) NG Mass (mg)	Mass of NG Detected (mg)	Recovery
18-May-09	Weathered 1	46	17	11	65%
18-May-09	Weathered 2	36	13	8.6	66%
Average					**66%**
16-Mar-09	Fresh 1	16	5.8	5.9	102%
16-Mar-09	Fresh 2	10	3.8	3.7	97%
16-Mar-09	Fresh 3	11	4.1	4.0	98%
16-Mar-09	Fresh 4	13	4.7	4.6	98%
16-Mar-09	Fresh 6	71	26	26	100%
Average					**99%**

5 Discussion

As we mentioned earlier in this report, the energetics residues deposition rate for the AT4 was significantly higher than that found for any other weapon system we have tested. Table 7 summarizes the results of testing we have done with mortars, howitzers, a tank, and small arms. Those results are then compared to the AT4 results presented here and to results from the M72 LAW and Carl Gustav rockets tested by DRDC in Canada. The results are generalized to the propellant constituents of concern, NG and DNT.

Table 7. Comparison of various firing point residues loads.

Weapon System	Propellant	Analyte	Load/ Rnd (g)	Residues/ Round (mg)	Residues/ Load
Howitzers					
105-mm	M1-I & II	DNT	42	34	8×10^{-2} %
155-mm	M1	DNT	275	1.2	5×10^{-4} %
Mortars					
81-mm	M9	NG	30	1,000	3.5%
120-mm	M45	NG	26	350	1.4%
Leopard Tank[2]					
105-mm (MIS)	M1	DNT	300	6.7	2.2×10^{-3}%
105-mm (Trays)	M1	DNT	300	7.8	2.7×10^{-3}%
Small Arms					
5.56-mm Rifle	WC844	NG	0.16	1.8	1.10%
5.56-mm MG[1]	WC844	NG	0.16	1.3	0.79%
7.62-mm MG	WC846	NG, DNT	0.27	1.5	0.56%
9-mm Pistol	WPR289	NG	0.040	2.1	5.44%
12.7-mm MG[1]	WC860 & WC857	NG	1.5	11.	0.73%
Shoulder-fired Rockets					
84-mm Carl Gustav[3]	AKB 204	NG	140	20,000	14%
66-mm LAW[4]	M7	NG	22	42	0.1%
84-mm AT[4]	AKB 204	NG	130	95,000	73%

[1] Averages loads and residues from ball and tracer rounds in linked ammunition.

[2] Preliminary results. (Ampleman et al. in prep)

[3] Thiboutot et al. (2008a)

[4] Thiboutot et al. (2008b)

We have found in the past that weapon systems which have longer barrels, rifled barrels, or larger propellant loads generally have a lower percentage of their propellant deposited as residues. This is likely due to the higher temperatures and pressures generated in these types of armaments. By contrast, a recoilless design such as the shoulder-fired rockets has a short, non-rifled, open-ended design, meaning pressures and temperatures can only build up within the rocket motor.

It is interesting to note that for the DRDC's tests of the M72 LAW rocket, the residue per round deposition rate is two orders of magnitude lower than for the AT4. The M7 propellant of the LAW rocket contains up to 8% ammonium perchlorate, a strong oxidizing agent. The propellant is obviously burning much more efficiently than propellant used with the AT4, which contains no oxidizing agent. A strong oxidizer may be required for efficient propellant consumption in a recoilless weapon design. There may be some problems associated with this inefficient burning process such as unreliability and the failure to hit a target.

Looking at the results from the May sampling, the estimated mass in the DU is about half what we found directly after firing the rockets. The two large segments recovered in May had lost 33% of the NG they originally contained. Smaller propellant particles are likely to more readily leach NG as compared to larger particles, especially for unburned particles, because the smaller particle's surface area to mass ratio is higher. The majority of the residues were smaller particles, thus the diffusion of NG from the estimated mass in May is likely higher on average than reflected in the 33% value obtained for the larger segment. Thus, the 52% reduction in NG over the backblast area is plausible. It is important to note that we did not take a baseline sample of the area prior to snowfall so we are uncertain if NG was present below the snow cover on the soil at the test location prior to our test.

6 Conclusions

Training with the AT4 shoulder-fired missiles will result in significant deposition and accumulation of nitroglycerin residues behind the firing position. Our tests indicated that more than 70% of the propellant is not consumed during operation of the weapon. On AT4 ranges with fixed firing positions, the propellant residues may build up to hazardous levels, an issue that will have to be addressed by range managers. Furthermore, leaching of NG from the unburned propellant may cause a groundwater contamination problem. Developing a rocket motor that burns propellant more efficiently would result in less energetic residue mass. Additional testing of rockets in the U.S. Army arsenal is warranted based on the results of this test.

References

Ampleman, G., S. Thiboutot, M.E. Walsh, M.R. Walsh, A. Gagnon, and A. Marois (in prep) *Energetic residues from the firing of a Leopard main battle tank*. Technical Report DRDC Valcartier (number pending). Val-Bélair, QC: Defence Research and Development Canada (DRDC)-Valcartier.

Brochu, S., I. Poulin, D. Faucher, E. Diaz, and M.R. Walsh. 2009. *Environmental assessment of small arms live firing: Study of gaseous and particulate residues*. Poster presentation, 237th ACS National Meeting, Salt Lake City, UT. 22-26 March 2009.

Clausen, J., J. Robb, D. Curry, and N. Korte. 2004. A case study of contaminants on a military range: Camp Edwards, MA, USA. *Environmental Pollution* 129:13-21.

Diaz, E., D. Gilbert, D. Faucher, A. Marois, and A. Gagnon. 2008. *Gun propellant residues dispersed from static artillery firings of LG1 Mark II and C3 105-mm howitzers*. Technical Report DRDC Valcartier TR 2007-282. Val-Bélair, QC: DRDC-Valcartier.

Hewitt, A.D., T.F. Jenkins, T.A. Ranney, J.A. Stark, M.E. Walsh, S. Taylor, M.R. Walsh, D.J. Lambert, N.M. Perron, N.H. Collins, and R. Kern. 2003. *Estimates for explosives residues from the detonation of army munitions.* ERDC/ CRREL TR-03-16. Hanover, NH: USACE Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL).

Hewitt, A.D., T.F. Jenkins, M.E. Walsh, M.R. Walsh, and S. Taylor. 2005. RDX and TNT residues from live-fire and blow-in-place detonations. *Chemosphere* 61:888-894.

Jenkins, T.J., T.A. Ranney, P.H. Miyares, N.H. Collins, and A.D. Hewitt. 2000a. *Use of surface snow sampling to estimate the quantity of explosives residues resulting from land mine detonations*. ERDC/CRREL TR-00-12. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL).

Jenkins, T.J., T.A. Ranney, M.E. Walsh, P.H. Miyares, A.D. Hewitt, and N.H. Collins. 2000b. *Evaluating the use of snow-covered ranges to estimate the explosives residues that result from detonation of army munitions*. ERDC/CRREL TR-00-15. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL).

Jenkins, T.J., M.E. Walsh, P.H. Miyares, A.D. Hewitt, N.H. Collins, and T.A. Ranney. 2002. Use of snow-covered ranges to estimate explosives residues from high-order detonations of army munitions. *Thermochimica Acta*, 384: 173–185.

Jenkins, T.J., A.D. Hewitt, M.E. Walsh, T.A. Ranney, C.A. Ramsey, C.L. Grant, and K.L. Bjella. 2005. Representative sampling for energetic compounds at military training ranges. *Environmental Forensics* 6: 25–55.

Jenkins, T.J., A.D. Hewitt, C.L. Grant, S. Thiboutot, G. Ampleman, M.E. Walsh, T.A. Ranney, C.C. Ramsey, A.J. Palazzo, and J.C. Pennington. 2006. Identity and distribution of residues of energetic compounds at army live-fire training ranges. *Chemosphere* 63:1280-1290.

Jenkins, T.J., A.D. Hewitt, S.R. Bigl, S. Taylor, D.J. Lambert, D.K. MacMillan, J.L. Clausen, and N.M. Perron. 2007. Sampling of various types of firing point areas for propellant residues at several military reservations. Chapter 3 in T.F. Jenkins et al. *Characterization and fate of gun and rocket propellant residues on testing and training ranges: Interim Report 1*. ERDC Technical Report TR-07-1. Vicksburg, MS: USACE Engineer Research and Development Center (ERDC). Available at: http://libweb.wes.army.mil/uhtbin/hyperion/ERDC-TR-07-1.pdf (accessed Oct. 2009).

Racine, C.H., M.E. Walsh, C.M. Collins, D.J. Calkins, B.D. Roebuck, and L. Reitsma. 1992. *Waterfowl mortality in Eagle River Flats, Alaska: The role of munitions residues*. CRREL Report 92-5 Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL).

Thiboutot, S., G. Ampleman, A. Gagnon. A. Marois, T.F. Jenkins, M.E. Walsh, P.G. Thorne, and T.A. Ranney. 1998. *Characterization of antitank firing ranges at CFB Valcartier*. WATC Wainwright, and CFAD Dundurn. DREV-R-9809. Val-Bélair, QC: DRDC-Valcartier.

Thiboutot, S., G. Ampleman, A. Marois, A. Gagnon, D. Gilbert, V. Tanguay, and I. Poulin. 2007. *Deposition of gun propellant residues from 84-mm Carl Gustav rocket firing*. DRDC Valcartier TR 2007-408, Unclassified. Valcartier, Quebec, Canada: Defence Research and Development Canada.

Thiboutot, S., G. Ampleman, A. Marois, A. Gagnon. D. Gilbert, V. Tanguay, and I. Poulin. 2008a. Energetic residues deposition from 84-mm Carl Gustav antitank live-firing. In *Characterization and fate of gun and rocket propellant residues on testing and training ranges: Final report*. T.F. Jenkins and S.R. Bigl, eds. Technical Report ERDC TR-08-1. Vicksburg, MS: USACE Engineer Research and Development Center. Available at (accessed Oct. 2009): http://libweb.wes.army.mil/uhtbin/hyperion/ERDC-TR-08-1.pdf.

Thiboutot, S., G. Ampleman, A. Marois, A. Gagnon, and D. Gilbert. 2008b. Deposition of nitroglycerin from the live firing of M72 A5 66-mm rockets. In *Proceedings of the 2008 SERDP & ESCP Partners in Environmental Technology Technical Symposium and Workshop*, Washington, DC, 2-4 December 2008.

U.S. Army. 1994. *Army ammunition data sheets: Artillery ammunition (FSC 1310, 1315, 1320, 1390)*. Technical Manual TM 43-0001-28. Washington, DC: U.S. Government Printing Office.

U.S. Environmental Protection Agency (USEPA). 2006. Nitroaromatics, nitroamines, and nitrate esters by HPLC. SW846 Method 8330B Washington, DC: USEPA Office of Solid Waste. Revision 2, October 2006. Available at: www.epa.gov/epawaste/hazard/testmethods/pdfs/8330b.pdf (accessed Oct. 2009).

Walsh, M.E., and T.A. Ranney. 1998. *Determination of nitroaromatic, nitramine, and nitrate ester explosives in water using solid-phase extraction and GC-ECD*. USA CRREL Special Report 98-2. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL).

Walsh, M.E., C.M. Collins, C.H. Racine, T.F. Jenkins, A.B. Gelvin, and T.A. Ranney. 2001. *Sampling for explosives residues at Fort Greely, Alaska*. ERDC/CRREL Technical Report TR-01-15. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at: (accessed Oct. 2009) http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-01-15.pdf.

Walsh, M.E., C.M. Collins, A.D. Hewitt, M.R. Walsh, T.F. Jenkins, J. Stark, A.B. Gelvin, T.A. Douglas, N. Perron, D.J. Lambert, R.N. Bailey, and K. Meyers. 2004. *Range characterization studies at Donnelly Training Area, Alaska: 2001 and 2002* ERDC/CRREL Technical Report TR-04-3. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at (accessed Oct. 2009):http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-04-3.pdf.

Walsh, M.E., C.A. Ramsey, C.M. Collins, A.D. Hewitt, M.R. Walsh, K.L. Bjella, D.J. Lambert, and N.M. Perron. 2005. *Collection methods and laboratory processing of samples from Donnelly Training Area firing points, Alaska 2003*. ERDC/CRREL Technical Report TR-05-6. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at (accessed Oct. 2009): http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-05-6.pdf.

Walsh, M.E., C.M. Collins, C.A. Ramsey, T.A. Douglas, R.N. Bailey, M.R. Walsh, A.D. Hewitt, and J.L. Clausen. 2007. *Energetic residues on Alaskan training ranges*. ERDC/CRREL Technical Report TR-07-9. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at (accessed Oct. 2009): http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-07-9.pdf.

Walsh, M.R. 2007. *Explosives residues resulting from the detonation of common military munitions: 2002-2006*. ERDC/CRREL Technical Report TR-07-2. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at: http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-07-2.pdf (accessed Oct. 2009).

Walsh, M.R., M.E. Walsh, C.A. Ramsey, and T.F. Jenkins. 2005a. *An examination of protocols for the collection of munitions-derived explosives residues on snow-covered ice*. ERDC/CRREL Technical Report TR-05-8. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at: http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-05-8.pdf (accessed Oct. 2009).

Walsh, M.R., S. Taylor, M.E. Walsh, S.R. Bigl, K. Bjella, T.A. Douglas, A.B. Gelvin, D.J. Lambert, N.M. Perron, and S.P. Saari. 2005b. *Residues from live-fire detonations of 155-mm howitzer rounds*. ERDC/CRREL Technical Report TR-05-14. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at: (accessed Oct. 2009) http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-05-14.pdf.

Walsh, M.R., M.E. Walsh, C.M. Collins, S.P. Saari, J.E. Zufelt, A.B. Gelvin, and J.W. Hug. 2005c. *Energetic residues from live-fire detonations of 120-mm mortar rounds*. ERDC/CRREL Technical Report TR-05-15. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at (accessed Oct. 2009): http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-05-15.pdf.

Walsh, M.R., M.E. Walsh, C.A. Ramsey, R.J. Rachow, J.E. Zufelt, C.M. Collins, A.B. Gelvin, N.M. Perron, and S.P. Saari. 2006. *Energetic residues deposition from 60-mm and 81-mm mortars*. ERDC/CRREL Technical Report TR-06-10. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at: http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-06-10.pdf (accessed Oct. 2009).

Walsh, M.R., M.E. Walsh, S.R. Bigl, N.M. Perron, D.J. Lambert, and A.D. Hewitt. 2007a. *Propellant residues deposition from small arms munitions*. ERDC/CRREL Technical Report TR-07-17. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at: (accessed Oct. 2009) http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-07-17.pdf.

Walsh, M.R., M.E. Walsh, and C.A. Ramsey. 2007b. *Measuring energetics residues on snow*. ERDC/CRREL Technical Report TR-07-19. Hanover, NH: USACE Engineer Research and Development Center (ERDC-CRREL). Available at (accessed Oct. 2009): http://libweb.wes.army.mil/uhtbin/hyperion/CRREL-TR-07-19.pdf.

Wingfors, H., C. Edlund, L. Hägglund, A. Waleij, J. Sjöström, R.-M. Karlsson, P. Leffler, U Qvarfort, M. Ahlberg, S. Thiboutot, G. Ampleman, R. Martel, W. Duvalois, A. Creemers, and N. van Ham. 2006. *Evaluation of the contamination by explosives and metals in soils at the Alvdalen Shooting Range – Part II: Results and discussion*. Scientific Report FOI-R-1877-SE. Stockholm, Sweden: FOI/Swedish Defence Research Agency.

Acronyms and Abbreviations

AcN	acetonitrile
C4	91% RDX, 9% oil
CA	Canadian Army
Composition B	60% RDX, 39% TNT, 1% wax
CRREL	Cold Regions Research and Engineering Laboratory
DNT	Dinitrotoluene (2,4-dinitrotoluene)
DoD	U.S. Department of Defense
DRDC	Defence Research and Development Canada
DU	decision units
EC	ethyl centralite
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
ER	Environmental Restoration
ERDC	Engineering Research and Development Center
FP	Firing Point
GPS	global positioning system
HEAT	high-explosive anti-tank
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
HPLC	high-performance liquid chromatography
LCS	Laboratory Control Spike; Laboratory Control Sample
MDU	meta-decision unit
MI	multi-increment
MIS	multi-increment sample
MMR	Massachusetts Military Reservation
MMRP	Military Munitions Response Program
MS	Matrix Spike
MSD	Matrix Spike Duplicate
NC	nitrocellulose
NG	Nitroglycerin
OTP	outside-the-plume
PE	Performance Evaluation
PETN	Pentaerythritol tetranitrate

QA Quality Assurance
QC Quality Control
RDX Hexahydro-1,3,5-trinitro-1,3,5-triazine
RSD Relative Standard Deviation
SERDP Strategic Environmental Research and Development Program
SPE solid-phase extraction
TNT 2,4,6-Trinitrotoluene
USACE U.S. Army Corps of Engineers
USEPA U.S. Environmental Protection Agency
UXO Unexploded Ordnance

Appendix A: Munitions Data

Table A1 contains information relevant to the munitions used during the test covered in this report. Propellant loads for the analytes of concern are given in Table 1 (page 7).

Table A1. Munitions data.

NSN	DODIC	Nomenclature	Lot No.	Drawn for tests
1315-01-245-4950	C995	Cartridge, 84 Millimeter: M136 (AT4) and Launcher	FFV89C001-045B	6

Note: Munitions were drawn from inventory, Ammunition Supply Point, Ft. Richardson, AK.
Ref.: US Army (1994).

Figure A.1. Unexploded AT4 projectile fired in March found downrange of target.

Appendix B: Analytical Results - March

Table B1 contains sampling data for the test conducted on snow at the 40MM/AT4 (40/90) Range at Fort Richardson on 16 March 2009. Table B2 contains the results of the analyses.

Table B1. AT4 firing point sampling data.

Sample	Scoop Size (cm / side)	Sample Type	# of Increments	Samplers' Initials	Filtrate Vol. (mL)	# of Filters	Notes
FRA09-01	10	Background	36	MRW	1,180	1	
FRA09-02	10	FPT-2	40	AG/JB	1,840	1	
FRA09-03	10	FPT-2	40	AG/JB	1,857	1	Rep 1
FRA09-04	10	FPT-1	38	AG/JB	1,650	1	Rep 2
FRA09-05	10	FPT-1	38	AG/JB	1,710	1	Rep 1
FRA09-06	10	OTP-D:3-6	40	MRW/ST	1,590	2	Rep 2
FRA09-07	10	OTP-D:3-6	40	MRW/ST	1,522	1	Rep 1: 3-6
FRA09-08	10	OTP-D:0-3	40	MRW/ST	1,370	1	Rep 2: 3-6
FRA09-09	10	OTP-D:0-3	40	MRW/ST	1,300	1	Rep 1: 0-3
FRA09-10	10	OTP-B:3-6	46	MRW/ST	2,030	1	Rep 2: 0-3
FRA09-11	—	BLANK 1	—	MRW	1,000	1	Rep 1: 3-6
FRA09-12	10	OTP-B:3-6	46	MRW/ST	2,045	1	
FRA09-13	10	OTP-B:0-3	39	MRW/ST	1,810	1	Rep 2: 3-6
FRA09-14	10	OTP-B:0-3	39	MRW/ST	1,800	1	Rep 1: 0-3
FRA09-15	15	Plume B/U	31	MEW/GA	2,620	1	Rep 2: 0-3
FRA09-16	10	Plume D/S	50	MRW/ST	1,000	1	Subsurface
FRA09-17	10	Plume D/S	50	MRW/ST	1,015	1	Rep 1
FRA09-18	10	Plume D/S	51	MRW/ST	1,140	1	Rep 2
FRA09-19	10	Plume B/S	100	MEW/GA	4,270	1	Rep 3
FRA09-20	10	Plume B/S	100	MEW/GA	4,180	1	Rep 3
FRA09-21	10	Plume B/S	100	MEW/GA	4,635	1	Rep 1
FRA09-22	20	Plume B/S	31	MEW/GA	4,380	1	Rep 2
FRA09-23	—	BLANK 2	—	MRW	1,000	1	Rep "4"
End of Samples							

Codes:	
B: Backblast area behind the firing point Background: Background sample of surface snow prior to tests; BLANK: Blank ultra-filtered water "sample" D: Downrange of firing point	FPT: Firing Point Transect OTP: Outside The demarcated Plume (X-Y m) Plume: The visually demarcated main Plume S: Surface sample U: Subsurface sample

Table B2. Sample analytical results (NG) for AT4 firing point.

Sample	NG Mass in Sample					NG Mass in Plume	
	Filtrate Portion			*Filter Portion*			
	Total (mg/L)	Total (mg)	Calculated (mg/m²)	Total (mg)	Calculated (mg/m²)	Total (mg)	Average (mg)
FRA09-01	*-ND-**	—	—	*-ND-*	—	—	
FRA09-02	*-ND-*	—	—	*-ND-*	—	—	
FRA09-03	*-ND-*	—	—	*-ND-*	—	—	*-ND-*
FRA09-04	*-ND-*	—	—	0.0054	0.014	0.39	
FRA09-05	*-ND-*	—	—	*-ND-*	—	—	0.19
FRA09-06	0.02	0.029	0.071	5.8	14.6	3,800	
FRA09-07	0.02	0.024	0.060	0.69	1.7	470	2,100
FRA09-08	0.35	0.48	1.2	0.052	0.13	320	
FRA09-09	0.52	0.67	1.7	11	28	7,200	3,800
FRA09-10	0.1	0.18	0.40	0.31	0.66	290	
FRA09-11	*-ND-*	—	—	*-ND-*	—	—	
FRA09-12	0.1	0.20	0.42	0.55	1.2	440	360
FRA09-13	0.17	0.31	0.79	3.2	8.1	2,100	
FRA09-14	0.25	0.45	1.2	0.43	1.1	540	1,300
FRA09-15	0.26	0.67	1.0	1.4	2.0	1,200	1,200
FRA09-16	4.7	4.7	9.4	49	98	42,000	
FRA09-17	3.9	4.0	8.0	29	59	26,000	
FRA09-18	4.3	4.9	10	40	78	34,000	34,000
FRA09-19	12	49	49	1,400	1,400	580,000	
FRA09-20	12	50	50	1,300	1,300	540,000	
FRA09-21a	12	54	54	1,400	1,400	600,000	
-21b	13	60	60				
-21c	12	55	55				
-21 Avg.	12	56	56	1,400	1,400	600,000	570,000
FRA09-22	11	49	39	1,100	900	380,000	530,000
FRA09-23	*-ND-*	—	—	*-ND-*	—	—	
End of Samples							
*ND: Not detected during sample analysis							

Appendix C: Analytical Results - May

Table C1 contains the analytical results for the May 2009 samples obtained in the backblast area. The results in Tables C1 are for NG, the major constituent of concern recovered from the samples. The decision unit (DU) area was 30 x 30 m, or 900 m^2.

Table C1. Analytical results for May 2009 backblast area samples.

	09FRA04	09FRA05	09FRA06	Mean
Sample Mass <2-mm size fraction	1,900 g	1,500 g	960 g	1,500 g
Sample Mass >2-mm size fraction	1,400 g	1,100 g	61 g	1,000 g
Total Sample Mass	3,300 g	2,700 g	1,600 g	2,500 g
NG Conc. in <2-mm fraction: Lab Rep 1	17 µg/g	13 µg/g	9.0 µg/g	13 µg/g
NG Conc. in <2-mm fraction: Lab Rep 2	16 µg/g	12 µg/g	10 µg/g	13 µg/g
NG Conc. in <2-mm fraction: Mean of Reps	16 µg/g	12 µg/g	9.0 µg/g	13 µg/g
NG Conc. in >2-mm fraction: Mean of Reps	0.18 µg/g	0.14 µg/g	0.66 µg/g	0.33 µg/g
NG Mass Recovered in Sample: <2-mm fraction	31,000 µg	19,000 µg	9,000 µg	20,000 µg
NG Mass Recovered in Sample: >2-mm fraction	257 µg	160 µg	400 µg	270 µg
Total Mass of NG in Sample	31 mg	19 mg	94 mg	20 mg
Estimated Area Sampled	710 cm^2	710 cm^2	710 cm^2	710 cm^2
Mass / Unit Area	430 mg/m^2	270 mg/m^2	130 mg/m^2	280 mg/m^2
Estimated NG Mass in 30-m x 30-m Decision Unit	390,000	240,000	120,000	250,000

Appendix D: Images of Propellant Segments

The following images were taken of segments of the AKB 204 propellant strips that fuel the AT4 rockets. These segments were recovered following the firing point test. These images were taken with a camera through a microscope. Images from March 2009 were of segments recovered directly after the firing test. The May 2009 images are of segments recovered following resampling of the area after two months. Weathering effects on the segments are obvious, with color change and leaching evident at the edges. Further electron- and photo-micgrograph work by Dr. Susan Taylor of CRREL will be done with these particles as part of her SERDP project on propellants.

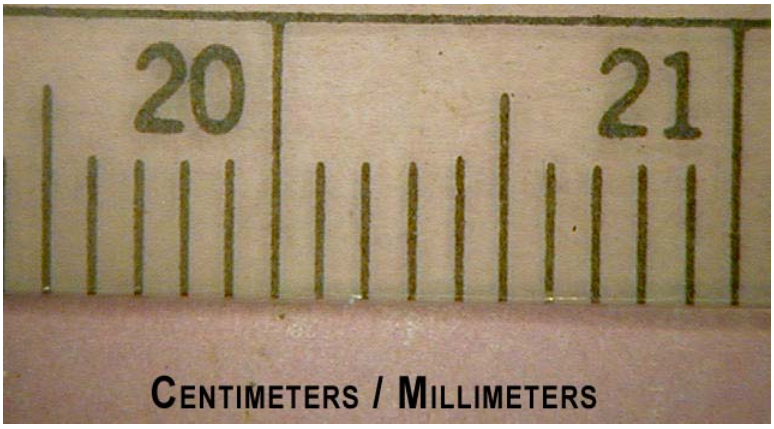
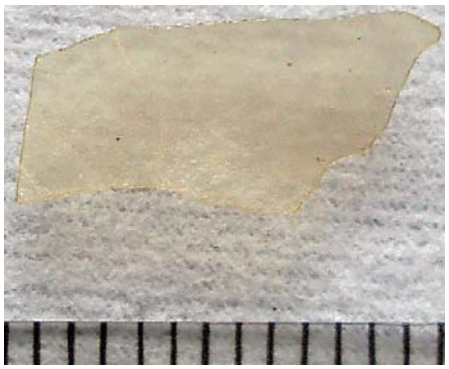


Figure D.1. Scale for 6x magnifications.

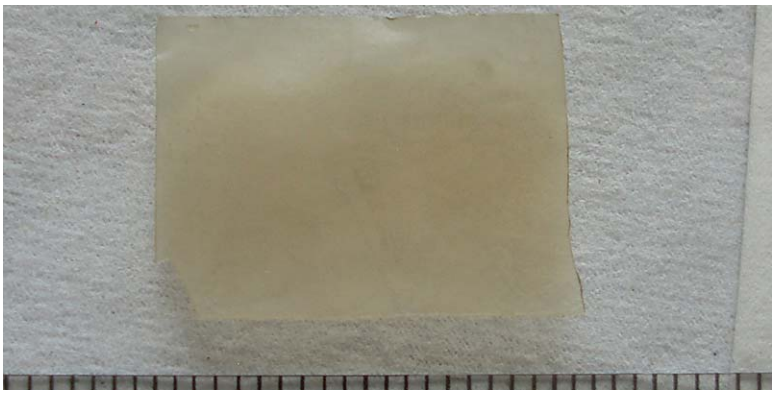
D.2a. Propellant segment image with 6x magnification.



D.2b. Propellant segment image taken without microscope (mm scale).

Figure D.2. Images of post-firing fresh propellant segment #4 collected in March 2009

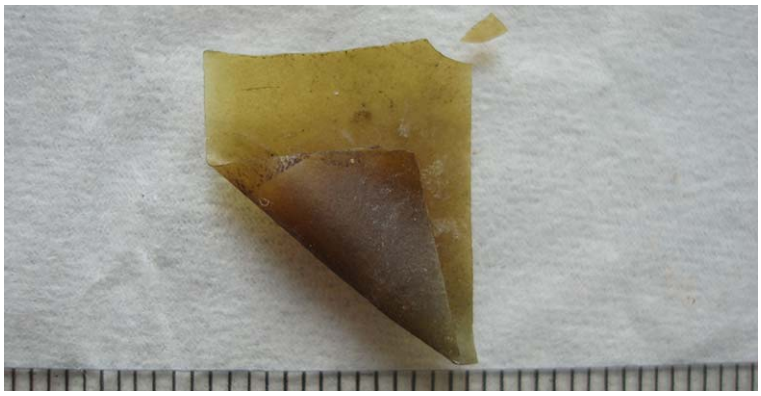
D.3a. Propellant segment image taken with 6x magnification.



D.3b. Propellant segment image taken without microscope (mm scale).

Figure D.3. Images of post-firing fresh propellant segment #6 collected in March.

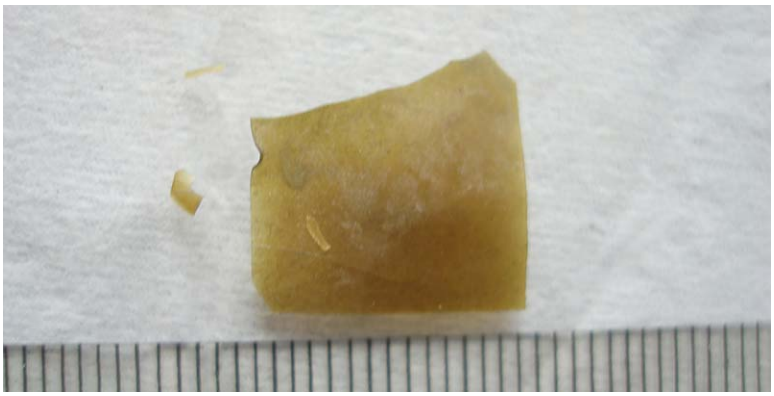
D.4a. Propellant segment image taken with 6x magnification.



D.4b. Propellant segment image taken without microscope (mm scale).

Figure D.4. Images of weathered propellant segment #1 collected in May from backblast area.

D.5.a. Propellant segment image taken with 6x magnification.



D.5.b. Propellant segment image taken without microscope (mm scale).

Figure D.5. Images of weathered propellant segment #2 collected in May from backblast area

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (From - To)
December 2009	Final Technical Report	

4. TITLE AND SUBTITLE
Propellant Residues Deposition from Firing of AT4 Rockets

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Michael R. Walsh, Marianne E. Walsh, Sonia Thiboutot, Guy Ampleman, and Jeffrey Bryant

5d. PROJECT NUMBER
SERDP ER-1481

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Research and Development Center (ERDC)
Cold Regions Research Engineering Laboratory (CRREL)
72 Lyme Road
Hanover, NH 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER
ERDC/CRREL-TR-09-13

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Strategic Environmental Research &
Development Program
901 N Stuart Street
Suite 303
Arlington VA 22203

10. SPONSOR/MONITOR'S ACRONYM(S)
SERDP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Military live-fire training missions utilize a variety of energetic materials that are never completely consumed during firing. In March 2009, tests were conducted at Fort Richardson, Alaska, to determine the residues related to the firing of AT4 anti-armor shoulder-fired rockets. Six rockets were fired from the same firing position on the snow-covered range. Replicate multi-increment samples were collected from the snow surface behind and downrange of the firing point in each of eight decision units. Samples were analyzed and results composited to derive an estimate of the mass of unreacted energetics. Total estimated per-round deposition rate of nitroglycerin (NG) for the M136 AT4 rocket is 95 g/round, or 73% of the original NG load. This indicates that the propellant burn efficiency for the AT4 is poor, with much propellant not consumed during firing. In subsequent May 2009 samples, we found approximately one-third of the NG had leached out of the propellant fragments since March. Large propellant strip segments collected in May contained 67% of the nominal NG of the original propellant, and we hypothesize that even more had leached from the more numerous, smaller segments. Canadian tests of the similar Carl Gustav rocket also indicate high rates (> 14%) of unburned propellants.

15. SUBJECT TERMS
propellants, residues, energetics, firing points, shoulder-fired rockets, munitions, nitroglycerin, snow, deposition rate, leaching

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
Unclassified	Unclassified	Unclassified		50	